WHAT'S NEW OVER THE PAST YEAR?

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Abstract: Astronomical discoveries of the past year are reviewed. Solar system topics include planetary spacecraft missions, comets, and near-earth asteroids. The effect of increasing resolution by using active optics on earth-based telescopes is outlined in many areas, including globular clusters, the galactic center, and supermassive stars. Among other topics are the unsuccessful searches for brown dwarfs and the prospect of comprehensive stellar opacity tables.

They're not going to let me talk about the best thing of the year, which is of course the Neptune Flyby. I was prohibited from that but told Dave I was going to show to a slide of it anyway. You're going to get a far better lecture than anything I could supply by Randii Wessen in the next couple of days. But it's certainly worth a look. It's worth a lot of looks, certainly one of the most spectacular scientific experiments ever undertaken by anyone before. It winds up being an incredibly beautiful object that we are just beginning to understand. But since I'm not allowed to talk about it, you can at least look at it.

I'm going to range over a wide, wide field here, including some new discoveries from this year, and some things that are continuing projects in which progress is made little by little from one year to the next. This of course was the year of Mars. I understand you last met a little over a year ago, but I'm going to bring it up anyway, because the planet went through this wonderful, favorable opposition at the last autumnal equinox. This photograph appeared on the cover of Sky and Telescope and is probably the best ever taken from the ground. One thing you are going to see throughout this whole talk is what I would call a quest for resolution. It is perhaps the most important single development that has taken place over the last few years. You are beginning to see the effects of it even here [photo of Mars] where you are simply going to high altitudes with superb instruments and taking very good photographs. We are going to see resolution vastly better than this as time proceeds.

Now, of course, the real boon to planetary science involves three space probes; two are on their way at this point. The Magellan Craft is on its way to Venus—which you see here in an image taken some years ago. It just shows the upper cloud belts, through which you look to see lower cloud belts. You can't see the surface of this body at all. You all know it is beautiful in the southwestern sky at this time. The revelation of what Venus is all about comes through the use of radar. Here you see a global radar shot of two continental size blocks, Ishtar Terra up here, Aphrodite Terra down here and what appear to be continents surrounded by ocean basins. There actually aren't any oceans because temperatures hover around 800 degrees Fahrenheit.

A close-up view shows Ishtar Terra and the Maxwell Mountains, the highest peaks on the surface of Venus. The resolution, however, is not terrific. It's the sort of thing that you might see photographically from an earth-orbiting satellite, or a weather satellite; you don't see very much. What Magellan is going to do is to image Venus very close up with a resolution that will probably approach 200 meters, such that you could see this college building on the surface of the ground. That is going to produce some absolute revelations in the study of Venus. It's supposed to arrive sometime next year, August 1990, and of course everybody's going to keep their eyes open for this one. Here's a photograph of it, seen orbiting around Venus with the brilliant sun in the background. It's a pity you can't actually see these things close up. The artists did do a wonderful job.

Then we've got failed spacecrafts, the unfortunate Phobos 1 and 2 that the Soviets launched. Phobos 1 died enroute; Phobos 2 actually took a picture of Phobos and then died. They simply lost control of it and never got it back. The solar panels drifted away from the sun and they couldn't get the craft rotated back before all the batteries died, and there's no chance of recovering it anymore at all. Yet we do at least see a photograph of a genuine asteroid here. Phobos and Deimos are certainly asteroids that orbit about Mars. We do have better pictures taken by U. S.-launched vehicles but I'm afraid that's about all we got out of this one.

You may have heard, however, that Galileo launched in spite of all the (I hope I don't—or maybe I hope I do—insult somebody) nuclear nuts that tried to keep it down. Anyway, if we manage to get it off on its way, it will arrive at Jupiter after a very long time. It's due on Pearl Harbor Day 1995, Sept. 7 for those of you who listen to George Bush. We've got a spectacular view of the planet Jupiter already, but this is going to do wondrous things for us. Not only is it going to drop a probe into Jupiter, it's going to map the cloud belts and the satellites of Jupiter. It's on its way. It's on its way in a weird direction. If you want to go to Los Angeles by jet from Champaign-Urbana, you fly to Dayton first, then you transfer and you go to L.A. from there. Galileo is doing the same thing. It's going to go to Venus first and then it's going to go back in the other direction because we don't have enough rocket power in this country to launch it directly. The problem was that Galileo was supposed to be launched aboard a Centaur rocket with the Shuttle. The Centaur rocket is a liquid hydrogen fueled craft. After the explosion of the Challenger, they decided maybe it wasn't terribly safe to have liquid hydrogen aboard, although I'm not sure it really would have made much difference one way or the other given a disaster of that magnitude. So they had to go to a lower power rocket and use gravity assists of Venus and the Earth to send Galileo to Jupiter. There's a shot of the Galileo craft in the shop with its large radio antenna at the top. It's a fairly large instrument, larger than Voyager. There you can see the workers, to put it a little bit in perspective. There is the orbit: it is launched from the Earth, it gets slung by Venus, and then back to the Earth again, and then around here to an asteroid, around back to the Earth, and every time it passes one of these planets, it gets a gravity assist. When it's finally at Jupiter, it will release its probe here. The Galileo will go into orbit around Jupiter and drop the probe between these clouds and belts. Here's a spectacular view. Of course what the nuclear people were worried about is that the NASA dynamics people would miss, and it would come crashing into the Earth and pollute the planet for all time with about 30-40 grams of plutonium or however much is in the spacecraft.

Well there is a beautiful painting of what it might look like upon arrival. This is a heat shield below the probe that is dropping into Jupiter. Of course there are parachutes to slow it down so we will have several minutes probe time as it examines such things as the temperature and density structure of the atmosphere. This is an enormously complex planet, with a solid interior, and liquid metal hydrogen down there below the cloud belts. It has an enormously complex meteorology as I'm sure you have all seen, and is a link perhaps between the real planets—the ones like ours—and the brown dwarfs and the stars themselves. Jupiter only fails by a factor of fifty of being a star. It doesn't have enough heat in its core o produce nuclear reactions.

From Jupiter, and since I'm not allowed to talk about you know what, we finally wind up at Pluto. This has been a fascinating year for Pluto. There is a file photograph on which you can see it moving. That's about the only view you can get of it with a reasonable telescope on Earth. You can't really resolve it very well because it's exceedingly small. But the real news about Pluto itself is that its orbit has been discovered to be chaotic. We're beginning to find that most of the orbits of planets are probably chaotic. This means that you can't predict the position of Pluto much more than a few million years into the future. As good as we have the position, it is not good enough. Very very tiny changes in the positionings of Jupiter, Uranus, you know what, and even Pluto will cause it to be wildly off its predicted position—perhaps by half an orbit after ten million years. The old nineteenth century view was that if you give me the coordinates of all the atoms of the universe I will tell you everything that is going to happen in the entire history of the universe from there on. It ain't true. This is what the science of chaos is slowly discovering. There are rules which will govern it, but the point is that we really can't predict what is going to happen. The meteorological equivalent is that a butterfly shakes its wings in Africa and you get a hurricane in North America. That of course is an exaggeration, but the fact is that these orbits over a long term are probably unpredictable by anyone at any time.

This close up view of Pluto shows it and its marvelous satellite, Charon. It is about 10% the mass of Pluto, making this a genuine double planet, much more so than the Earth-moon system. A few years after Charon was discovered, we found that it and Pluto went into a series of mutual eclipses. So we can use the eclipses to measure orbital characteristics, to give some idea of surface features on Pluto, and to measure masses, the radii and so on; because of course there's no way we're going to send a spacecraft to this thing for probably the next twenty or thirty years at the rate things are going. Pluto is now inside of Neptune's orbit and it will remain there until 1999. That provides a good view, because it is up to about 13th magnitude now. It's not too difficult to see; it's accessible with a 12 inch telescope in a very dark site.

Chiron is a curious body which was discovered orbiting between Saturn and Uranus. It was thought for a long time to perhaps represent a different kind of asteroid belt that was in between the two planets. It was discovered this year that what we've got is not really an asteroid; it appears to be active, spewing gas off its surface. Now this thing is something like two hundred kilometers wide; the size of a small moon of Saturn. Try to imagine what it would look like if it were in an orbit like Halley's Comet. It would be quite spectacular, perhaps similar to some of the comets that we saw in the 19th or even the 18th centuries, the daylight comets, the ones that you could look up at noon and see with the naked eye.

Speaking of comets, they have had some good reviews this year as well. Here's something you might not have seen before, a radio photograph, a radio image of a comet. This is Comet Wilson. Since you've discussed the computer facilities on the campus of University of Illinois, it might be kind of interesting to look and see some of the work that is being done locally. This is a view in the OH line of Comet Wilson, which was taken by Lou Snyder of our department with the Very Large Array in New Mexico. What he's been interested in is ultimately looking for bio-molecules in comets. There is a very strong feeling, one that has developed over many years, that life was seeded on the Earth by comets which contained complex organic molecules. During the Halley flyby they found with a mass spectrograph that there were massive atoms being spewed out of Halley. Nobody knows yet what they are. Of course the link will be found by looking at these comets with radio telescopes to see what kind of heavy molecules there are. So far, we are only up to formaldehyde. Nevertheless, that is a significant advance that has taken place over the last couple of years. We're also beginning to find where these comets are coming from. It used to be thought that all comets were coming out of the Oort comet cloud. The Oort comet cloud extends perhaps twenty thousand astronomical units away from the sun. The idea is that nearby passing stars and nearby passing gas clouds, interstellar gas clouds, stir up the comet cloud and sent a few of them into the Earth. They then come in on these long elliptical orbits like Wilson which you saw last year, like Bennett, and some of the others that we have had over the last few years. The idea was that occasionally a few of these comets would pass close to Jupiter, and would be captured by it into a near solar orbit, having an aphelion near Jupiter, perhaps like Giacobini-Zinner that you see here, a short period comet with a 6.6 year period. Well, the distribution we find really isn't quite that way. It has become apparent that the short period comets are coming out of a disk of cometary material somewhere outside the orbit of Pluto, perhaps an indigenous disk. The Oort comet cloud is now thought to consist of comets thrown out of the early system by Neptune and Uranus. These are the original planetesimals out of which the solar system was made. There are two kinds of belts. The Oort comet cloud, which has been made into a spherical distribution by tidal forces in the Galaxy, and this inner disk that is still probably here from the time of the origin of the solar system. Giacobini-Zinner and several of the other short period comets, and perhaps even Halley, are coming out of that disk.

We move now back inwards to the sun, whose activity is up a lot. During March of last year we observed some of the greatest solar activity since perhaps the sixties, which was the greatest solar maximum (1959-1960) of all time, at least all recorded time. This shows you an immense solar flare of gas jetting off the surface of the sun in an ultraviolet image taken with Solar Max. I think the craft died within the last couple of weeks. This immense solar activity produced some spectacular effects on the ground. Wonderful auroras, the kind of which have not been seen down here at low altitudes since the sixties. If I may bore you with a bit of a reminiscence, when I was an undergraduate in college beginning to do some observing at the University of Michigan, latitude about 42 degrees, there were so many displays of Northern Lights that not only did you get bored with them, you didn't want to go out and look at them anymore; it was, "Oh my God, another Northern Lights display. We can't see the stars, we have to close up the dome, and we have to send everybody home." That's almost unbelievable now. Now you wait 20 years just to get a view of something like this. This is taken from Pennsylvania. It's remarkable.

You have probably seen this one before. This [a daylight meteor] is not news really; it took place in 1972. But asteroid 1989 FC, which passed within about 600,000 or so kilometers of the earth, not quite the distance of the moon is news. Maybe it would have looked something like this if it had hit the Earth. This is a daylight meteor, a daylight fireball that took place over the Grand Tetons in I think 1972. A number of amateur photographers captured it. This is not an ionization train as much as it is just the streak across the film made during the exposure time. The body itself is probably about the size of the building you are sitting in here. That's the best guess. Maybe the side of a barn or somewhere around there. Nobody really quite knows. Fortunately, it hit the Earth's atmosphere, skipped off, and went back into space. Well, 1989FC, which was quoted as a near miss in the paper, might have done something like this, which is scary folks. This photo is of the Praha Basin, which appears to be a gigantic meteor crater that occupies all of Czechoslovakia, is something like 300 kilometers wide, perhaps the largest known crater. It is probably about 2 to 3 billion years old; nobody is quite sure. It's going to happen again. I don't think anybody doubts it; we just hope that technology is great enough so that we can see it coming and blow it out of the sky a' la Starwars before it actually happens.

The middle part of this talk involves what I brought up in the early part of the lecture: the quest for resolution. We're building bigger telescopes. This is the dome of the Keck 10 meter telescope that will go onto Mauna Kea, Hawaii. This telescope is in a lot of trouble, by the way. It is segmented and consists of 30 or so mirrors. And they have not yet been able to complete any of the mirrors because they are all off-axis paraboloids, which are very difficult to construct. So it is sopping up a whopping amount of money. There's no doubt but that it will get done, but it is beginning to look more and more like a government military project the way it is going. Of course one must also mention the equivalent 16 meter telescope that the Europeans are putting in Chile. That's on line. It's not a segmented mirror, it's four 8-meter mirrors strung together so that you can electronically link them up and stack images. There are two things you want to get out of a large telescope: light gathering power and resolution. We can get the light gathering power. You can build them as big as you want. But it's tough to get the resolution because of the Earth's atmosphere. The 5 meter in California, the 200-inch, might be capable of .02 seconds of arc resolution. But what do you get? A half a second of arc because it's got to look through the Earth's turbulent atmosphere. So you are only getting half of what you want at this point by building a large telescope. We are beginning to find ways of achieving that resolution in spite of the earth's atmosphere. Well, one way of doing it is to launch a space telescope. The big news here is that we didn't do it yet. It's supposed to be done this year. The last update that I got was March of 1990; they will probably slip from there.

But as long as we're on the subject (this is a 2.3 meter telescope by the way) of space instruments, look at another. The International Ultraviolet Explorer, one of the fantastic successes of NASA, is one which is hardly known among the amateur population of the country. They should know much more about it. This is a 16-inch telescope that was launched simply to observe the spectrum in the ultraviolet below 3000 Angstroms, so you can't see anything through it. It has revolutionized stellar and galactic astronomy because it's showing things we had no way of getting at from the Earth at all. You've got to go into space. It was launched with a three-year design lifetime in 1976. It is now in its 13th year. It was launched with six stabilizing gyros. Of course we only need three; three were redundant. It is now—get this engineers—it's now working on two. It is being controlled in three directions by two gyroscopes. That is quite an achievement; and there are ways of controlling it with one when the next one dies. In the absence of the space telescope, this is all we've got out there for making deep space observations, the International Ultraviolet Explorer; a wonderful, wonderful instrument in geosynchronous orbit.

Of course if you're going to talk about space instruments, there it is, whether you like it or not, what we think maybe the space station might look like at some point, at least an artist's perception of it. Whether it will ever be used for astronomical observations or not, I don't know. It's hard to see how you could mount a telescope on it: somebody rolls over in bed, and the telescope moves. But I'm sure there are ways of doing it.

Returning to Earth, here is the three hundred foot radio telescope. Talk about news, I'll give you news. What happened to it? Well, what happened was the failure of some load bearing points right here that developed stress fractures. Of course they kept it painted and you couldn't see the fractures develop. This 300-foot, which was the biggest telescope on the North American continent, rather the biggest moveable one (it's a meridian instrument), made some wonderful discoveries over the years. It was also only supposed to have a few years of lifetime, and here we are fifteen years later, still working. It looked like it worked fine and then all of a sudden it just buckled. These bearing elements gave way and down it went. At least that was what the engineers say, but if you shop in the supermarket, you know better [space aliens did it].

This is the replacement. As soon as it fell down Senator Byrd said, "We are are gonna get another one." And within a couple of weeks they had the money for it. They are going to build a state-of-the-art off-axis paraboloid. This is the focus up here, at the top. The idea is keep the feed and support units off the dish because that eliminates a lot of diffraction effects. It really cleans up the imagery, and it's a neat design. They're expecting it to be 100-meters in diameter. The inner 60 meters or so good would be good down to 3mm, which gets you into the molecular ranges for spectroscopy. This should be quite an instrument when it is finished. We're all looking forward to it. The other 100-meter which is in Bonn, West Germany, is almost as good, but Lew Snyder who spent some time there, keeps saying they spend most of their time painting it, of course covering up the stress fractures, so you never get much time to observe.

Back to the quest for resolution. We're starting to learn how to use these telescopes in spite of our turbulent atmosphere. Here's a photograph of Messier 15 in Pegasus taken with U of I's 1-meter telescope. I thought I'd slip that in. It looks pretty dense in the center. Look into the middle of it, with a couple of different telescopes. This image was taken with an instrument in Hawaii. It's an ordinary one that you get with manual guiding, and has a resolution of about 0.8 seconds of arc. This is some of the best seeing on the face of the earth, on Mauna Kea in Hawaii. Here is the size of the seeing disk right here. This instrument is equipped with fast guider. They can actually keep up with the twinkling of the star 500 times per second. And when you do that together with some computer processing, you get down to 0.36 seconds of arc in the nucleus of this globular cluster.

Look at another example here. This one is with NTT, the New Technology Telescope operated by the European Southern Observatory. It uses active, or adaptive, optics. You reflect light to the Nasmyth focus here, off to the side. It goes into an image analyzer which actually keeps up with the shifting back and forth of a star. You then interactively feed that information into the support of the mirror, giving you a mirror which flexes and keeps up with the changing wavefront of the incoming stellar image, thereby de-twinkling the star. These things are beginning to work. They are beginning to work remarkably well. Here is Omega Centauri. If you've never seen this fourth magnitude globular cluster get yourself to the southern U.S. at least and look at it. You look out to the south and think: my goodness what is that, that big blob; it's the best globular cluster you've ever seen in your life. It has one million stars, and is probably the most massive globular cluster in the Galaxy. Look into the center of it. This photograph was made with a Schmidt telescope, and has a resolution of 2 seconds of arc. With the New Technology Telescope working at its best, we see to 0.18 seconds of arc. We want the Space Telescope largely for resolution, and you know within five years we may not need it. We didn't know this when we planned it. Of course the ST does a lot of things: it will also look in the ultraviolet and the infrared, which you can't see from the ground. That doesn't mean that we shouldn't launch it. We desperately need a 2 meter telescope in orbit if for no other reason to look in the UV. You also get away from the sky backgrounds. Remember there's a permanent aurora which is always lighting up the sky. Well, you can eliminate that as well. We still have constraints, but what we're achieving even now is quite remarkable.

We're doing some interesting work here in this area in our department at the U of I. Here's a laser at the back end of a 1 meter telescope. What they do is to zap the laser into the sodium layer about 70 kilometers above the earth's surface and create an artificial star. It's not good enough yet. This is the image of the laser 70 kilometers above the ground, in the sodium rich layer above the Earth. Eventually we will get that star image to sub-second of arc size in the atmosphere. They can then look at it with the telescope, look the twinkling of this artificial star, and use it with their interactive optics and rubber mirrors, and de-twinkle all the stars around it. They can place this star any place they like. For most of the adaptive optics systems you have to have a very bright star in the field of view, otherwise they won't work. If you look at a faint galaxy near the galactic pole, odds are you're never going to find a 10th or 12th magnitude star. But you can put your laser there and then look at it with your telescope to detwinkle the image. We're now talking a telescope that will get diffraction-limited images from the ground, 0.02 sec. of arc resolution, and boy is that ever going to revolutionize astronomy. That is where the effort is now beginning to go.

You've also got to deal with resolution in radio telescopes. There are two large radio telescope systems under development. This is the millimeter-wave interferometer at Cal Tech, which will begin to map out the sky in molecular radio lines so we can see how star formation is taking place. This is in competition with the BIMA array, being built by Berkeley, Illinois and Maryland which now consists of three radio telescopes at Hat Creek in Northern California, and after two years will consist of 6 radio telescopes operating in the millimeter range. You're now getting images almost as good as you are able to get optically. This is an example of the object called Sharpless 109 and you can see the optical image this way and the radio image perpendicular to it. What you are looking here is a thick cloud of dust much like the disk of our solar system, and perpendicular to that, light coming out and illuminating the surrounding area. Here is the center of our galaxy as seen with this array with something like a few seconds of arc resolution. The galactic center is here, looking for all the world like a miniature spiral galaxy as gas spirals down into what may be a black hole; a million-solar-mass black hole at the center.

We're beginning now to talk about stars. Let's talk about brown dwarfs a bit. Look at Jupiter: maybe it's a brown dwarf. Brown dwarfs are one of the enigmas of modern stellar astronomy. They have been looked for now for the past several years. They're failed stars. The limit to nuclear burning in the core of a star is 0.08 solar masses. If you get it up above 0.08, you can get the temperature in the core of a star high enough to initiate the proton-proton, hydrogen fusion reaction. Then you have a star. Jupiter is only a few tens of thousands of degrees at the center and, you can't possibly do it. Below 0.08 solar masses the star will live for a while from its gravitational energy and should still be visible, although its energy is not coming from thermonuclear fusion. Those aren't brown dwarfs of course, these are the Hyades and Pleiades clusters up here. Here's Jupiter as it was last year, last January. What we want is a link between the planets and the stars. Is there a continuous distribution from the planets to the stars? How much of the missing mass of the Galaxy is tied up in brown dwarfs? Well it's a "now you see it, now you don't" situation, and nobody yet knows whether they're there. Look at the Pleiades a little bit closer up, and then look at them even closer, into the central region of it. And here's what's been counted as a brown dwarf. It's much brighter over here in the infrared than it is in the visual part of the spectrum because it's obviously a very very cool star. The people who wrote the paper say that they think there are a dozen brown dwarfs or so in the Pleiades, just on the basis of the brightness. A few other people look around the Taurus dark clouds, in the star forming regions, and say "Yeah, we think we see a few of them here." Another fellow looked at radial velocity variations in one star and said "I think I can see one." Then there was a paper just about a month ago that looked at 50 or 60 stars, at radial velocity variations, and the authors didn't find anything at all. Radial velocities, by the way are another news item. We're now looking at radial velocities down in the meters per second range in stars with some of the new technology that's being done. But they didn't see any brown dwarfs at all. Their conclusion was, "Well, I don't think there are any out there." At least if there are, there are very very few. So it depends upon what paper or what newspaper you read. So far there have been no confirmed cases of brown dwarfs. You really almost have to start with Jupiter and go down.

This next point gets quite technical: I think it took me a lecture of about a half an hour by Dimitri Mihalis in our department so I could understand exactly what these guys are doing. This isn't something that you're likely to read about in "Astronomy" or "Sky & Telescope" or anywhere else, yet it may revolutionize the stellar industry, and it is something you ought to at least be aware of. In order to construct a model of a star you've got to know the opacity of its gas. You've got to know how the light is being blocked on its way up. Globular cluster stars, for example, are smaller than main sequence stars of the same temperature because they have fewer metals. Fewer metals means that the light doesn't get blocked as easily; there's less radiation pressure, and the stars shrink. It turns out that the opacity of a star is critically dependent upon wavelength, because it depends exactly upon what atoms are in the star. You can't just say it is sort of a smooth function of wavelength. There's been a project going on for the last five years, and it has occupied 100 man-years of time. It is centered here in Urbana-Champaign, at University College London, in Caracas, Venezuela, and in a few other places. There are 20 people working on the project, which sounds terribly boring, to produce tables of opacity as a function of wavelength. Here's an example of the hideous complexity involved. When this is done, and it's almost finished now—the papers are starting to come out—when it's completed next year, it will probably revolutionize our ideas of stars and begin to explain away many anomalies involved in Cepheid variable stars, RR Lyrae stars, a whole bunch of other things. It has been an enormous project. It is literally chewing up people's careers, it's taking so much time. It requires vast computer power, the supercomputers for example, the Crays that we have here on this campus.

We all recognize this object. If this were Astronomy 100, I'd say "well what is this?" And everybody would say "The Crab Nebula". Oh no, it ain't. <u>That's</u> the Crab Nebula. This is the Southern Crab, otherwise called Heinize 2-104. I'm pleased to say that I'm part of the first large paper to come out on this object. There is a Mira variable star buried in thick dust down in the middle. It's what we call a symbiotic star, in this case a white dwarf in orbit around a Mira variable with gases flowing from the Mira, the giant star, onto the surface of the white dwarf which heats up. The hot spot in turn illuminates all of the surrounding gas that is flowing away from the Mira. It's a very weird object with huge density and temperature gradients within the cloud. At some point the Mira in the middle will probably turn into a particular type of planetary nebula. We may be looking at one way in which planetary nebulae are developed. I'll show you some of these later.

Again, the quest for resolution. You look at a galaxy and can see numerous very luminous stars. These particular ones have become known as luminous blue variables (LBVs). Everybody likes to use abbreviations. There are a half dozen here in M33. We also have a few in our own galaxy, P Cygni, a 4th magnitude star that was almost first in the year 1600, and Eta Carinae, in the southern hemisphere, which I will talk about in tomorrow afternoon's discussion. This is the Eta Carinae nebula up here: a beautiful, beautiful thing. It actually consists of a number of nebulae at different distances. Buried here in the middle is Eta Carinae itself. It's now sixth magnitude, but in 1860 it was of the first magnitude. This part of the sky contains Sirius, Canopus, and Eta Carinae, and it must have been an incredible sight. As it faded it ejected a shell of dust around it. You can't actually look through it to see the star. The shell makes it look like a cool F star, whereas in reality we think there's a B star of maybe a 100 solar masses at the core. You may remember a few years ago that there was a star called R136A that was thought to be supermassive: around of a thousand solar masses. We looked at it with interferometers to improve the resolution, and we saw that it was no more than a tight cluster of O and B stars. Eta Carinae is showing the same kind of behavior. Look here at the resolution. It's still a massive star, we think, but not as massive as we thought it was. This work was done through speckle interferometry, where you actually take very short photographs or images of stars as they twinkle and then let the computer determine what the star must have looked like to give it that speckle or twinkle pattern. It has been very successful in looking for binaries and in resolving stars like this one.

Of course, the supernovae continues to take the stand. This is Supernova 1987a in the Large Magellanic Cloud. This B supergiant exploded and reached the fourth magnitude. We continue to watch the light curve, which is largely produced by the decay of cobalt and nickel. Now it looks like the light curve is turning over and is now due to the decay of cobalt again. We'll be following this for many, many years. The supernova also produced a large number of light echos. Here's the Supernovae in the middle and you can see the radiation of the explosion striking other clouds of interstellar gas.

Supernovae of this kind should have pulsars at their centers like that in the Crab—the Northern Crab that is. One was found on one night of observation of the 18th or 19th magnitude beating at 1968.63 pulses per second. But it then disappeared. Either the cloud thickened to hide it, or the calibrations were bad and it was never found at all.

Speaking of collapsed stars, the X-ray binary in M15, consisting of a normal and collapsed star, has been located. Here we really see the need for resolution. The famed millisecond binary pulsar PSR 1957+20 is also seen here, in which the orbital motion has spun the pulsar up to 622 revolutions per second. It is called the Black Widow, as the pulsar is consuming its mate.

And speaking of supernovae, SN1885 in the M31 galaxy has been recovered. Here we see it as a black dot against M31's stellar background. The expanding cloud is rich in iron, which at the wavelength of the photo absorbs the background light.

Finally, on to the Universe at large. The Hubble constant always makes news. The value is not known well, with observed values that range from 40 kilometers/sec/mpc—on the West Coast—to 100 on the East. Here is the midwest we like an average since it coincides better with the ages of the globular clusters as calculated from stellar evolution theory. There is also a new way of determining the galaxies' distances. Here we see a photo of M81 and its planetary nebulae. Look at some close-ups of these beautiful objects as they appear in our own Galaxy. There is a well-defined maximum brightness for the set of planetaries in a galaxy, and thus they become standard candles and may provide some of the best available distances. Then there is the Incredible Disappearing Protogalaxy. It was thought to be a cloud of neutral hydrogen gas, and maybe a genuine nearby protogalaxy, which is quite unexpected. It would indicate that galaxies are still forming. But now there is evidence that it may merely be a gas-rich elliptical. The argument is far from over. And of course there was yet another record set in the search for the highest red shift. The galaxy 4C 41.17 has $z = 3.8$, indicating it is between 6 and 15 billion light-years away depending on the model of the universe you use. Then gaze into this photo of deep space. Here is a section of sky only 2 by 2 minutes of arc across covered with faint blue—or young— galaxies. There may be 20 billion of them.

It's been a fine year, with great news all the way from the Universe at large back to our own home planet. As usual some problems get resolved, and new ones take their places. Thank you.